GEORGIAN MEDICAL NEWS

ISSN 1512-0112

N0 10 (331) Октябрь 2022

ТБИЛИСИ - NEW YORK

ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии

საქართველოს სამედიცინო სიახლენი

GEORGIAN MEDICAL NEWS

Monthly Georgia-US joint scientific journal published both in electronic and paper formats of the Agency of Medical Information of the Georgian Association of Business Press. Published since 1994. Distributed in NIS, EU and USA.

GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.
GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.
ჟურნალი ინდექსირებულია MEDLINE-ის საერთაშორისო სისტემაში, ასახულია SCOPUS-ის, PubMed-ის და ВИНИТИ РАН-ის მონაცემთა ბაზებში. სტატიების სრული ტექსტი ხელმისაწვდომია EBSCO-ს მონაცემთა ბაზებიდან.

WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html

В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორთა საყურადღებოდ!

რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman** (**Кириллица**), ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ,რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ, რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი, მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი, წელი, ჟურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

Содержание:

THE STRESS IN THE ACL, ACL GRAFT, AND OTHER JOINT ELEMENTS WHILE WEIGHT-BEARING IN FULL EXTENSION DEPENDING ON THE POSTERIOR TIBIAL SLOPE

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Abstract.

The safety of early weight bearing after anterior cruciate ligament (ACL) reconstruction and the degree of posterior tibial slope (PTS) impact on ACL and ACL graft are still uncertain due to the limitations of previous studies.

The study aimed to evaluate the effect of PTS change on ACL and ACL graft stress.

We created the complex multicomponent static models of physiologically normal knee joint, taking into account the different PTS, the ligaments of the knee joint, including the ALL, articular cartilage, and menisci, literature data on muscle tension also with double-bundle ACL and single-bundle ACL graft to determine deformations and stress on the anatomical elements of the joint at a qualitatively new level. Stress in the knee structures was assessed using the finite element method separately with a 6 mm diameter double-bundle normal ACL and an 8 mm single-bundle ACL graft for the two variants of the tibial plateau slope: 5° and 13.9°.

Raising PTS from 5° to 13.9° increases stress in the ACL by 1.29 - 1.45 times and in the single-bundle ACL graft by 1.75 - 1.81 times in the upright position with knees in full extension. Stress in ALL increases with higher PTS by 1.58-2.00 times in the knee joint with double-bundle ACL and 1.93-2.02 times in the knee joint with single-bundle ACL graft while weight bearing in full extension. Increasing the PTS angle from 5° to 13.9° with healthy ACL stress in the meniscus increases by 1.05 - 1.34 times, and with a single-bundle ACL graft - by 2.04 - 2.30 times. Replacing the double-bundle ACL with the single-bundle ACL graft also causes an increase in its stress compared to intact ACL under all studied conditions.

Increased PTS and ACL reconstruction significantly increase stress in most knee anatomical elements while weight bearing in full extension. Even with a total weight of up to 150 kg, the critical value of stress for the rupture of the ACL graft from a one-time load is not achieved even after reducing its breaking load in 6 weeks. In the early postoperative period, the weakest link is the fixation of the graft with the interference screw. Cyclic load on the fully extended knee (regular walking) can provoke slipping out of the graft from under the interference screw.

Key words. Anterior cruciate ligament, ACL, posterior tibial slope, finite element analysis.

Introduction.

Rehabilitation after anterior cruciate ligament reconstruction (ACL) is still controversial. One of such controversial issues is the safety, onset time, and duration of weight bearing in full extension of the operated limb. There are numerous arguments for [1-6] and against [7-10] early weight bearing in full extension. One of the potential factors that are particularly often associated with a higher ACL load is a greater posterior tibial slope (PTS) [11-14]. However, not all studies have been able to confirm this [15].

But we are interested not so much in the increased risk of ACL damage at high PTS angles [11-13], as it is unlikely that such healthy individuals should be prohibited from exercising, but in the effect of increased PTS on ACL graft after plastic surgery [16], as it may affect the choice of allowable loads, optimal exercises, and deadlines for their start during postoperative rehabilitation, depending on the angle of PTS. Increased PTS can potentially increase the risk of ACL graft damage during early weight bearing in full extension. Thus, a significantly higher risk of ACL and ACL transplant damage in PTS of 12° and more is reported by Webb J. M. et al. (2013), Salmon L. J. et al. (2018) and Lee C. C. et al. (2018) [13,14,17]. However, there is almost no research on how much the load on the ACL and the ACL graft increases when combining a high PTS angle with an anterolateral ligament (ALL) rupture.

PTS averages 6.3° [18] to 13.6° [19] in different populations. Pangaud C. et al. (2020) and Webb J.M. et al. (2013) consider pathological PTS 12° and more [13,18]. And although higher PTS is often associated with higher anterior cruciate ligament (ACL) loads [11-14], not all studies have been able to confirm this [15]. The models used to evaluate the effect of PTS on ACL were significantly simplified, did not take into account the role of numerous anatomical elements, including anterolateral ligament, and did not compare the effect of PTS on normal double-bundle ACL and single-bundle ACL graft.

One of the fairly accurate methods for such an analysis is the finite element method. When comparing it with the experiment on the cadaveric knee joint, the ACL load difference was less than 11% [20].

The limitations of previous studies, the uncertainty regarding the safety of early weight bearing after ACL reconstruction, and the degree of PTS impact on ACL and ACL graft prompted us to conduct this investigation with the finite element method.

The study aimed to evaluate the effect of PTS change on ACL and ACL graft stress.

Materials and methods.

The knee joint model with 14 complex, curved shape elements was created using SolidWorks. We used the average size parameters of the bones [21-22] and menisci [23] and CT images of the real knee joint (after checking compliance with these averages) with the interslice interval of 0.5 mm for design. The model did not include cartilage on the articular surface of the tibia and the inner side of the patella due to the relatively insignificant role for this task [24-26].

For analysis and comparison, we considered two variants of the tibial plateau slope (Figure 1): 5° and 13.9°. Such angles were chosen as the minimum and mean normal PTS measured by conventional lateral radiographs (as the simplest and most practical method) according to Yoo JH et al. (2007) [27] and Medda S. et al. (2017) [28], rejecting the extreme results from the literature, and taking into account the statements of Salmon L. J. et al. (2018) and Lee C. C. et al. (2018) [13,17] about the danger of PTS greater than 12°. The study aimed to determine whether and to what extent the change in PTS affects the ACL and ACL graft even within normal limits. If such an effect is detected, it is logical to expect its increase with increasing PTS to abnormal values, which according to AL Juhani W. et al. (2020), can reach 23.9° in healthy individuals [19].

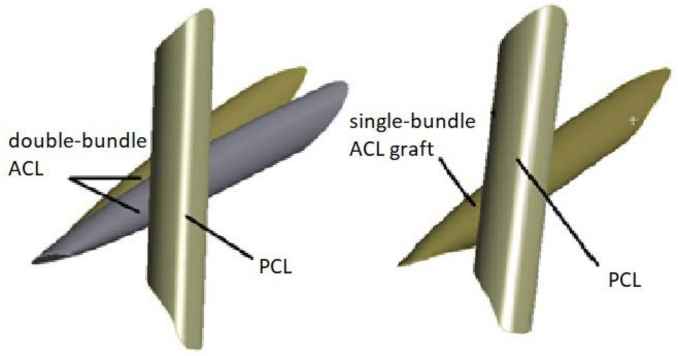


Figure.1. *Objects of the study: healthy double-bundle ACL and a single-bundle ACL graft.*

We assessed stress in the knee elements separately with a 6 mm double-bundle normal ACL and an 8 mm single-bundle ACL graft (Figure 1). Single bundle means a graft with all the fibers located in parallel and not at different angles, as in an intact ACL.

The ACL diameter averages 4.8 mm [29] to 8.3 mm [30]. Studies say that the average diameter of ACL in patients with ACL injuries is 2 mm less than in the general population (6.10 mm - 6.20 mm) [31,32]. We used this size to assess the risk of exercise and loads on the intact ACL. The diameter and cross-sectional area of a graft vary greatly depending on its type. It is the smallest for BTB grafts. For the most commonly used grafts of semi-tendons, it is optimally at least 8 mm (although in the real world, thinner grafts sometimes are also used) [33].

To analyze stresses and strains on the anatomical elements of the knee joint under normal physiology in the Ansys software, we set the mechanical properties of the anatomical elements of the knee joint - Young's modulus and Poisson's ratio of compact and spongy bone, cartilage, menisci, ligaments [25,34,35]. A finite element grid (2,079,911 nodes, 1,377,642 elements) was generated for both models. For more accurate calculations, the grid in the contact areas was condensed. The average size of the element is not more than 1 mm. The mean orthogonal quality for this model is 0.85, and the mean skewness is 0.23. Testing has shown that further condensing of the calculated grid does not affect the results. The cut parts of the elements of the knee joint we replaced with appropriate forces.

Muscles have been replaced by springs to simplify the model and speed up calculations. Efforts were applied at the springs' mounting points and directed along the direction of the springs (muscles) corresponding to the tabular values (Table 1) [36]. We performed the calculations for standing with a total weight of 75 kg, 100 kg, 125 kg, and 150 kg. We determined the total deformation, equivalent elastic deformation, and equivalent stress according to the constructed model.

Results.

To illustrate the equivalent stress, total displacements, and total deformation in the knee at a load of 75 kg (body weight) while weight bearing in full extension with double-bundle ACL and single-bundle ACL graft at PTS 5° and 13,9°, we presented the visual data in tabular form (Table 2).

It was found that using an even slightly thicker single-bundle ACL graft instead of a double-bundle ACL, and an increase in PTS add to stress in many structures of the knee joint, including ACL and ALL compared to baseline (double-bundle ACL and PTS 5°) even without changing the position of the knee joint while weight bearing in full extension. All the data on stress in the knee joint elements we presented in Table 3.

In Table 3 we see that the added weight unsurprisingly increases stresses on most elements of the system in proportion to the weight growth. The confirmation of the growing stress in ACL with increasing PTS is more interesting. We also see that replacing the double-bundle ACL with a single-bundle ACL graft also causes an increase in its stress compared to intact ACL under absolutely all studied conditions. Stress in ALL also increases slightly when the ACL is replaced by a single bundle ACL graft. Thus, the mathematical model demonstrates that ACL reconstruction does not reproduce the same biomechanics that a double-bundle ACL provides. However, the difference in stress is not as significant as with an increase in PTS.

Raising PTS from 5° to 13.9° increases stress in the ACL by

Table 1. *Muscle exertions while weight bearing in full extension [36].*

Muscles	**Muscle exertions [N] at weight**			
	75 kg	**100 kg**	**125 kg**	**150 kg**
m. gluteus maximus	0,75	1,25	1,95	2,93
m. gluteus medius	7,50	12,50	19,53	29,30
m. rectus femoris	3,75	6,25	9,77	14,65
m. vastus lateralis	0,75	1,25	1,95	2,93
m. vastus medius	0,75	1,25	1,95	2,93
m. vastus intermedius	0,75	1,25	1,95	2,93
m. semitendinosus	0,75	1,25	1,95	2,93
m. semimembranosus	7,50	12,50	19,53	29,30
m. biceps femoris short head	0,75	1,25	1,95	2,93
m. biceps femoris long head	7,50	12,50	19,53	29,30
m. soleus	18,75	31,25	48,83	73,24
m. gastrocnemius lateralis	7,50	12,50	19,53	29,30
m. gastrocnemius medialis	7,50	12,50	19,53	29,30

Table 2. *Equivalent stress, total displacements, and total deformation in the knee at a load of 75 kg (body weight) while weight bearing in full extension.*

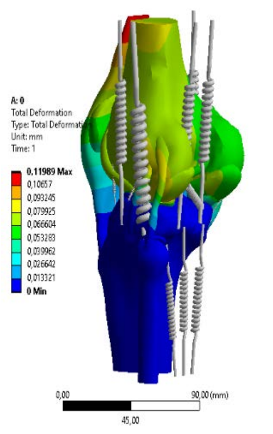
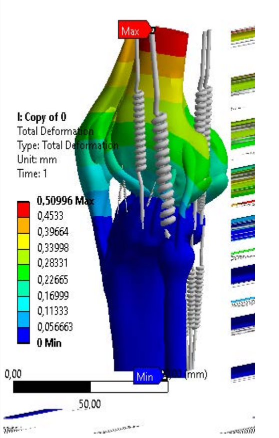
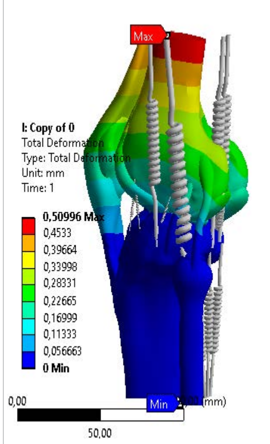
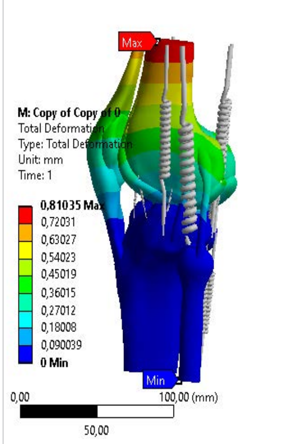
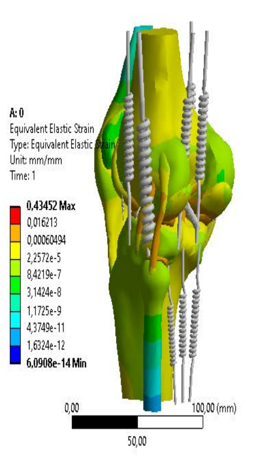
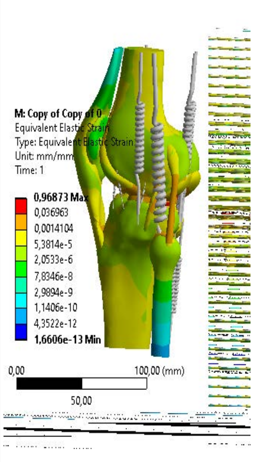
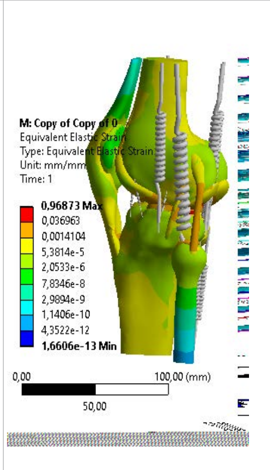
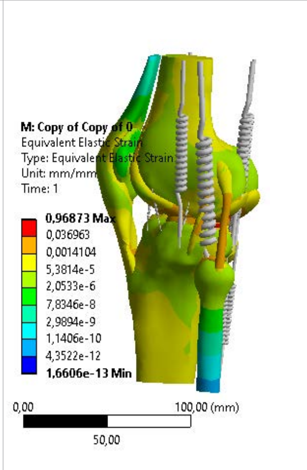
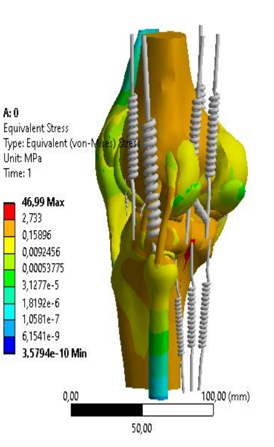
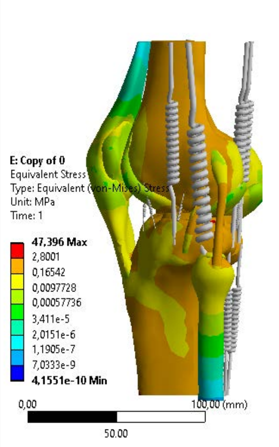
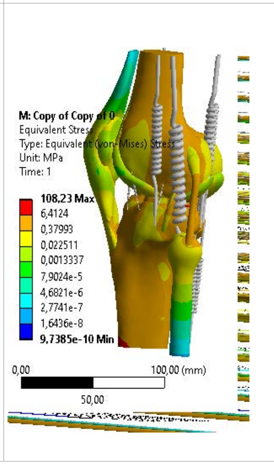
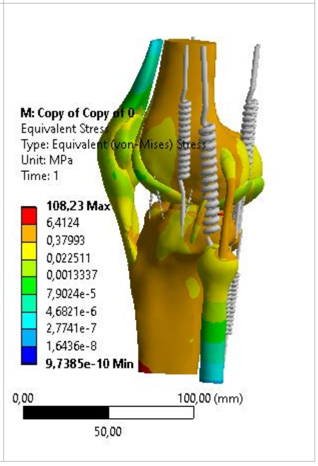
Parameter	PTS 5°		PTS °13,9	
	double-bundle ACL	**single-bundle ACL graft**	**double-bundle ACL**	**single-bundle ACL graft**
Total displacements				
Total deformation				
Equivalent stress				

Table 3. Stress in the knee joint elements depending on the load conditions and PTS.

The knee joint element	Stress (MΠa), while weight bearing in full extension at a load							
	PTS 5°				PTS 13,9°			
	75 kg	100 kg	125 kg	150 kg	75 kg	100 kg	125 kg	150 kg
ACL double-bundle	**2,33**	**3,06**	**3,78**	**4,67**	**3,39**	**4,28**	**5,17**	**6,06**
Single-bundle ACL graft	**2,49**	**3,21**	**3,93**	**4,82**	**4,49**	**5,81**	**7,12**	**8,43**
ALL (with double-bundle ACL)	**2,12**	**2,75**	**3,38**	**4,25**	**3,59**	**4,44**	**5,34**	**6,21**
ALL (with single-bundle ACL graft)	**2,37**	**2,99**	**3,62**	**4,49**	**4,58**	**5,95**	**7,31**	**8,68**
Menisci (with double-bundle ACL)	**46,99**	**62,65**	**78,31**	**93,98**	**62,74**	**69,57**	**83,96**	**98,35**
Menisci (with single-bundle ACL graft)	**47,39**	**63,21**	**79,03**	**94,82**	**108,23**	**136,69**	**135,16**	**193,63**
Bones of the knee joint (femur, tibia, patella) (with double-bundle ACL)	9,93	12,57	15,21	19,87	22,24	26,9	31,56	36,22
Bones of the knee joint (femur, tibia, patella) (with single-bundle ACL graft)	11,96	14,59	17,22	21,88	30,52	39,31	48,1	56,89
Patella tendon and quadriceps tendon (with double-bundle ACL)	1,48	1,77	2,06	2,96	5,66	6,53	7,42	8,36
Patella tendon and quadriceps tendon (with single-bundle ACL graft)	2,12	2,39	2,69	3,59	8,71	11,09	13,49	15,88
Cartilage of the femoral condyles (with double-bundle ACL)	9,49	13,61	17,73	18,99	12,44	12,66	13,02	13,51
Cartilage of the femoral condyles (with single-bundle ACL graft)	6,88	10,83	14,96	16,24	24,65	30,82	36,99	43,17
Posterior cruciate ligament (with double-bundle ACL)	1,35	1,73	2,11	2,71	2,81	3,39	3,97	4,55
Posterior cruciate ligament (with single-bundle ACL graft)	1,59	1,96	2,34	2,95	3,89	5,01	6,13	7,25
Lateral (fibular) collateral ligament (with double-bundle ACL)	2,92	3,62	4,32	5,84	7,96	9,48	11,01	12,54
Lateral (fibular) collateral ligament (with single-bundle ACL graft)	3,73	4,42	5,12	6,64	11,36	14,57	17,79	21,01
Medial (tibial) collateral ligament (with double-bundle ACL)	0,47	0,69	0,93	0,94	1,37	1,44	1,51	1,61
Medial (tibial) collateral ligament (with single-bundle ACL graft)	0,42	0,53	0,72	0,8	2,52	3,16	3,81	4,45

1.29 - 1.45 times depending on weight in the upright position with knees in full extension. When replacing a normal double-bundle ACL with even a slightly thicker single-bundle ACL graft, raising PTS from 5° to 13.9° affects its stress more catastrophically, increasing it by 1.75 - 1.81 times. Stress in ALL increases also significantly with higher PTS - 1.58-2.00 times in the knee joint with double-bundle ACL and 1.93-2.02 times in the knee joint with single-bundle ACL graft while weight bearing in full extension.

Most other joint elements also experience a significant increase in stress with raising PTS. Thus, when increasing the PTS angle from 5° to 13.9° with a healthy ACL, the stress in the meniscus increases by 1.05 - 1.34 times, and when replacing a normal double-bundle ACL with a single-bundle ACL graft - by 2.04 - 2.30 times.

Discussion.

High-quality physical therapy allows quick restoration of the athlete to continue training. But even when all possible efforts and resources are invested in it, there is still a limit due to the speed of biological processes in the body, which we can`t cross yet.

Most studies report the accelerated weight-bearing patients to have the better function in the early postoperative period. However, their function at two-year follow-ups was usually the same as in the late weight-bearing groups [7]. Nevertheless, the questionnaires and scales are not always able to fully describe the function and stability during intensive sports, especially rotational stability. The accelerated weight-bearing may theoretically increase the risk of knee laxity. So maybe we should select patients who need this early performance even with some chance of laxity, which can stay with the patient forever or lead to revision surgery, which is often two-step.

Breaking load for ACL allografts is, depending on their type, from 777 N to 4112 N [37]. The breaking load of BTB allograft with an average cross-sectional area of 67 mm is 1139 N, and the strength is 168 N/mm [38]. For allografts from tendons of the semi- group, it may be from 1 567 N to 4360 N [39]. Much less research on the strength of autografts. An autograft of a double folded m. semitendinosus tendon showed greater resistance to breaking load than other grafts - 1029 N (11.5% and 10.3% more than BTB and quadriceps tendons, respectively) [40]. But the tensile strength of a graft decreases with time. And in the first months, the weakest link may be the fixation strength by an interference screw or other fixator [41,42]. Cyclic load on the graft is another risk factor that can cause it to break or slip with less effort.

Depending on many factors, the fixation strength of the interference screw is only 174 N - 315 N [42], which is the weakest element of the system immediately after surgery. In the tibial canal, the graft is often fixed with an interference screw, with both cortical layers drilled. Therefore, at least at one end of the graft, we get a fixing strength of an average of 251 N (minimum - 182 N). However, there are other studies on the strength of tendon fixation with an interference screw - 506 N to 758 N for BTB [43].In a meta-analysis of graft tears and violations of fixation, Chen N.C. et al. (2007) showed that it could happen already at a load of 235 N [44]. At cyclic load on 8 mm ACL graft in 9 mm tunnel fixed with 8 mm screw in case of short (25 mm) screw graft slipping from under the screw in some cases occurred at loads up to 150 N and at loads up to 450 N - in all cases even with long 45mm screws [45].

The destructive load for ACL grafts decreases in the first 4-12 weeks after surgery [46]. Thus, the strength of the graft six weeks after surgery is reduced by 27% [47]. So, we can expect its rupture in this period even at lower loads. Knowing the average cross-sectional areas of ACL and ACL grafts [48,49], we can calculate the minimum loads for rupturing the weakest allografts immediately after installation (777 N) for fresh autografts from doubled m. semitendinosus tendon (1029 N) and graft slipping from under the interference screw (150 N for cyclic load, 182 N for one-time). And after six weeks, we can assume a decrease in graft strength by an additional 27%.

The cross-sectional area of the ACL is from 30 mm^2, and the graft of semi-tendons is from 58.2 mm^2. Breaking load for a healthy ACL has been studied less, and it is unlikely to expect its exceeding when standing even with weight. The breaking load for ACL grafts is 1029N / 58.2mm^2 = 17.68MPa in the first weeks after surgery. After six weeks, the breaking load on the ACL graft due to the degradation of the latter decreases and is already from 751 N / 58.2 mm^2 = 12.90 MPa. The risk increases with increasing PTS, patient`s weight or use of added weights, and graft diameter decreasing. While weight bearing in full extension of the knees, even with a total weight of up to 150 kg, the critical stress value for ACL rupture from a one-time load is not achieved. But in the first weeks after the operation, the weakest link is the fixation of the graft with an interference screw. Unfortunately, we cannot transfer critical loads to MPa because they are not linked to the cross-sectional area. But given that they are 4-6.9 times smaller than the breaking load, this may indirectly indicate the possibility of graft slipping from under the interference screw even when standing, especially if the patient is standing or walking regularly. Even a few millimeters of graft elongation can reduce stability in the knee joint.

Thus, with the help of finite element analysis of ACL stress, it has been shown that throughout the postoperative period, a patient weighing even 150 kg and with normal or moderately increased (up to 13.9°) PTS can sometimes be allowed to step on the lower extremity in the orthoses blocked in extension. We cannot expect the graft to break. However, many steps, even with small loads while weight bearing in full extension, should be considered in terms of ACL or ACL graft resistance to cyclic load (walking). Graft slipping out is also a risk in such a situation. The risk is proportional to the patient's weight and PTS. This risk decreases after six weeks and disappears after 12.

Conclusions.

Complex multicomponent static models of physiologically normal knee joint taking into account the PTS, the ligaments of the knee joint, including the ALL, articular cartilage, and menisci, literature data on muscle tension also with double-bundle ACL and single-bundle ACL graft allowed to determine deformations and stress on the anatomical elements of the joint at a qualitatively new level.

Increasing PTS significantly increases stress in the ACL and even more on the ACL graft while weight bearing in full extension. Nevertheless, even with a total weight of up to 150 kg, the critical value of stress for the rupture of the graft ACL from a one-time load is not achieved even after reducing its breaking load in 6 weeks.

But in the early postoperative period, the weakest link is the fixation of the graft with the interference screw. Cyclic load on the fully extended knee (regular walking) can provoke slipping out of the graft from under the interference screw.

We should select the rehabilitation program individually for each patient considering the technique of surgery (choice of graft, type of fixation, intraoperative factors), the term from injury to surgery (tissue adaptation, compensatory mechanisms), the presence of concomitant injuries (cartilage or menisci), age, type and level of activity, the physical condition of the patient, motivation, and expectations of patients.

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